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ANALYSIS OF STATIC PERFORMANCE CHARACTERISTICS OF A RIGID PLAIN CIRCULAR JOURNAL BEARING WITH MICROPOLAR FLUID

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ABSTRACT

This paper presents the effect of additives in lubricants on the static characteristics such as load and side flow of a 25mm radius journal bearing with clearance of 0.04mm. The effect of micro-polarity is evaluated by introducing two non-dimensional parameters, the coupling number (N^2) and characteristic length (Lm)

KEYWORDS: Lubricants, Journal Bearing with Clearance, Micro-Polarity

INTRODUCTION

The design of journal bearings is of considerable importance to the development of rotating machinery. Journal bearings are essential machine components for compressors, pumps, turbines, internal-combustion-engines, motors, generators, etc. In its most basic form a journal bearing consists of a rotating shaft (the journal) contained within a close fitting cylindrical casing (the bearing). Generally, but not always, the bearing is fixed in a housing. The journal and bearing surfaces are separated by a film of lubricant (liquid or gas) that is supplied to the clearance space between these two surfaces. The clearance space is generally quite small and has four major functions:

- To permit assembly of the journal and bearing.
- To provide space for the lubricant.
- To accommodate unavoidable thermal expansions, and
- To tolerate any shaft misalignment or deflection.

The fundamental purpose of a journal bearing is to provide radial support to a rotating shaft. Under load, the centers of the journal and the bearing are not coincident but are separated by a distance called the eccentricity. This eccentric arrangement establishes a converging-wedge geometry which in conjunction with the relative motion of the journal and the bearing permits a pressure to be developed by viscous effects within the thin film of lubricant and thus produces a load carrying capability. **Hydrodynamic journal bearings**, also called self-acting bearings, depend entirely on the relative motion of the journal and the bearing to produce film pressure for load support.

Earlier studies have been carried out for journal bearings considering the behavior of lubricant as Newtonian fluids and neglecting the deformation of bearing shell[1,2] later on studies were conducted considering the deformation of the bearingshell (Elastohydrodynamic lubrication). [3,6]

Further the improvement in various properties of commercially available Lubricants by way of mixing different additives paved the ways for mathematical studies on Micropolar fluids. [4,5]. The additives are considered as suspended micro structure particles in the lubricant and in case of journal bearing where clearance space and film thickness are quite low the effect of these cannot be ignored.

ANALYSIS

In this work studies are carried out on the performance characteristics of a rigid circular bearing with micropolar lubricant. The Reynolds equation is used for the hydrodynamic flow field and the Non-Newtonian effect is introduced by deriving a generalized Reynolds equation. The transient motion trajectories of the rigid bearing with non Newtonian lubricants have been obtained using linearized equation of the disturbed motion of the journal. The static performance characteristics in term of eccentricity ratio, attitude angle, minimum fluid film thickness, power loss, and load has been obtained by using a MATLAB program.

Modified Reynolds Equation

The general form of the governing equations for the steady state motion of incompressible micropolar fluids, as given Eringen's theory are

$$V. (\rho V) = 0 \tag{1}$$

$$-VP+ (\lambda_o+ \mu+\mu_r) V (V.V) + (\mu + \mu_r) \Delta V +2\mu_r(V \text{ x } W) = 0 \tag{2}$$

$$(c_o + c_d -c_a)V (V.W) + (c_d+c_a) \Delta W +2\mu_r (V+ V -2W) = 0 \tag{3}$$

The above equations are the equation of conservation of mass, conservation of linear momentum., and conservation of angular momentum, respectively, where V is the velocity vector and W is the microrotational velocity vector, **p** is the pressure **ρ** is the mass density, μ and λ_o are dynamic Newtonian viscosity and the second Viscosity coefficient; respectively, while μ_r represents the dynamic microrotation viscosity. c_o, c_a and c_d are the coefficients of angular velocity. Now

$$V= (v_x,o,v_y),\ W = (w_x,o,w_y) \tag{4}$$

Since the height of the fluid film is very small compared to the bearing radius we can neglect the curvature of the fluid film, then Eqs. (2) and (3) are reduced to

$$(\mu+\mu_r)\frac{\partial^2 v_x}{\partial y^2} + 2\mu_r\frac{\partial w_z}{\partial y} - \frac{\partial P}{\partial x} = 0 \tag{5a}$$

$$(\mu+\mu_r)\frac{\partial^2 v_z}{\partial y^2} - 2\mu_r\frac{\partial w_x}{\partial y} - \frac{\partial P}{\partial z} = 0 \tag{5b}$$

$$(c_a+c_d)\frac{\partial^2 w_x}{\partial y^2} + 2\mu_r\frac{\partial v_z}{\partial y} - 4\mu_r w_x = 0 \tag{5c}$$

$$(c_a+c_d)\frac{\partial^2 w_z}{\partial y^2} - 2\mu_r\frac{\partial v_x}{\partial y} - 4\mu_r w_z = 0 \tag{5d}$$

The boundary conditions at bearing and journal surfaces are

$$V_{x/y=0}=U,\ V_{z/y=0}=W_{x/y=0} = W_{z/y=0} = 0 \tag{6}$$

$$V_{x/y=h} = V_{z/y=h} = W_{x/y=h} = W_{z/y=h} = 0 \tag{7}$$

When we solve eqs. (5a)- (5d) with the above boundary conditions, the velocity components are obtained. Substituting the velocity components in the Eq. (1), and integrating across the film results in the generalized form of the Reynolds equation for micropolar fluids, given below

$$\frac{\partial}{\partial x}\left[\frac{\psi(N,\Lambda.h)}{\mu}\frac{\partial P}{\partial x}\right] + \frac{\partial}{\partial z}\left[\frac{\psi(N,\Lambda.h)}{\mu}\frac{\partial P}{\partial z}\right] = 6\mathrm{U}\frac{\partial h}{\partial x}$$

$$\psi(N,\Lambda.h) = h^2 + 12\Lambda^2 h - 6N\Lambda h^2 coth\left(\frac{Nh}{2\Lambda}\right) \tag{8}$$

Where

$$\Lambda = \left(\frac{c_a + c_d}{4\mu}\right)^{1/2}, N = \left(\frac{\mu_r}{\mu + \mu_r}\right)^{1/2} \tag{9}$$

In Eq. (8). h is the film thickness in the clearance space of the lobe with the journal in a state of steady state and is expressed as

$$h_i = \frac{1}{\delta} - X_j \cos\theta - Y_j \sin\theta + \left(\frac{1}{\delta} - 1\right)\cos(\theta - \theta_0^i) \tag{10}$$

(X_i, Y_j) are the steady state journal center coordinates and θ_o is the angle of lobe line of centers. δ is the preload in the bearing, the ratio between minor Clearance when journal and bearing geometric centers are coincident to conventional radial clearance.

N is a dimensionless parameter, the coupling-number, it relates the coupling of the linear and angular momentum equations. It can be shown that 0<N<1 .Large N means, the individuality of the substructure becomes significant. The parameter Λ represents the interaction between the micropolar fluid and the film-gap and is called the characteristic length. As Λ approaches zero the effect of microstructure becomes less important. When it vanishes, Eq. (8) reduces to the classical form of the Reynolds equation for a Newtonian fluid.

Introducing the following dimensionless quantifies:

$$L_m = \frac{c}{\Lambda}, \theta = \frac{x}{R}, \mathrm{h} = \frac{\mathrm{h}}{\mathrm{C_m}}, \mathrm{Z} = \frac{\mathrm{z}}{\mathrm{L}}, \mathrm{P} = \frac{\mathrm{PC_m^2}}{\mu \mathrm{UR}} \tag{11}$$

Eq. (8) can be written in nondimensional form as

$$\frac{\partial}{\partial\theta}\left[\frac{\psi(N,\Lambda.h)}{\mu}\frac{\partial P}{\partial\theta}\right] + \left(\frac{R}{L}\right).\frac{\partial}{\partial z}\left[\frac{\psi(N,\Lambda.h)}{\mu}\frac{\partial P}{\partial z}\right] = 6\mathrm{U}\frac{\partial h}{\partial\theta}$$

$$\psi(N,\Lambda.h) = h^3 + \frac{12h}{L_m^2} - \frac{6Nh^2}{L_m} coth\left(\frac{Nhl_m}{2}\right) \tag{12}$$

RESULTS AND DISCUSSIONS

Static Performance Characteristics

- **Load Capacity**

Variation of the non-dimensional load carrying capacity as a function of the non-dimensional characteristic length Lm for different values of coupling number N^2 (0.1, 0. 3, 0. 5, 0. 7 and 0.9) and eccentricity ratios ranging from 0.2 to 0.7 are depicted in figure 1 to 6. We can see that for any coupling number (N^2), the load carrying capacity reduces with characteristic length (Lm) and the load approaches to Newtonian fluid in the limiting case. It clearly shows that there is an appreciable rise in the load carrying capacity at small values of Lm. figure 1 to 6 also show that for any characteristic length (Lm), the load carrying capacity increases as the coupling number increases. The load carrying capacity reduces as coupling number reduces. At low characteristic length a plain circular journal bearing lubricated with micropolar fluid provides maximum load carrying capacity as compared to the Newtonian fluid

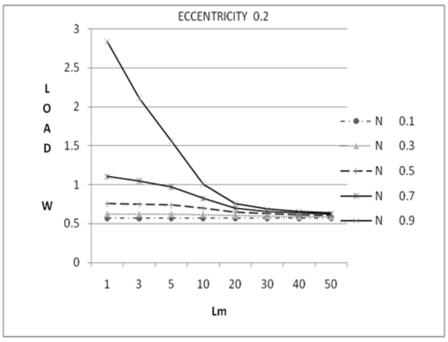


Figure 1

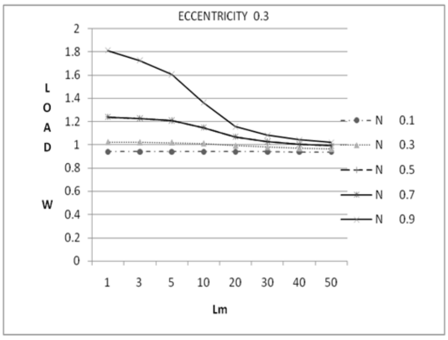


Figure 2

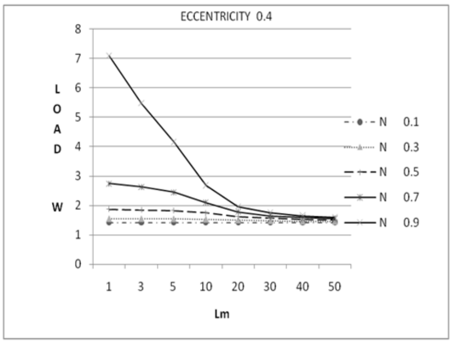
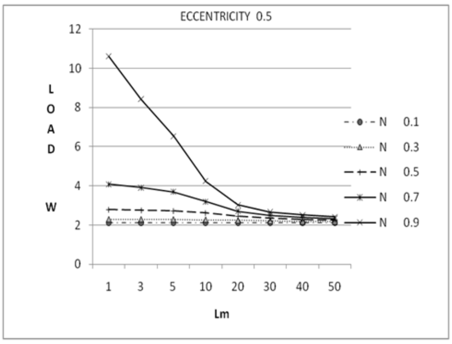


Figure 3



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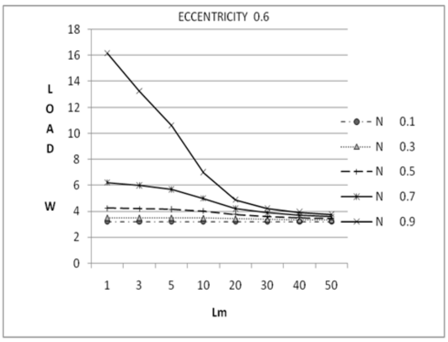


Figure 5

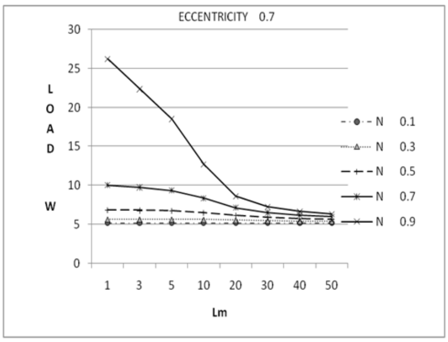


Figure 6

Note: Instead of N the value of N2 are shown in graph

- **Side Flow**

Variation of the side flow as a function of the non-dimensional characteristic length Lm for different values of coupling number N^2 (0.1, 0.3, 0.5, 0.7 and 0.9) and eccentricity ratios ranging from 0.2 to 0.7 are depicted in figure 7 to 12. The decrease in side flow, though not much can reduce the heat dissipation capacity of the lubricant.

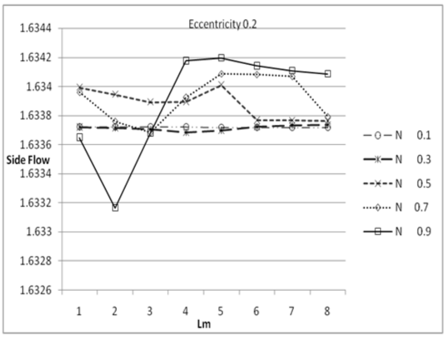


Figure 7

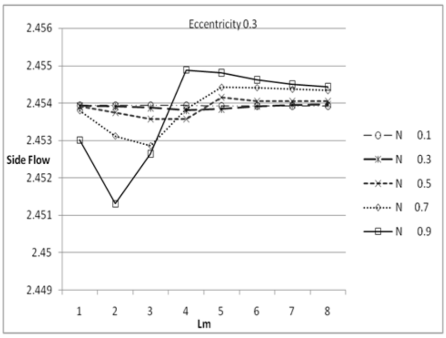


Figure 8

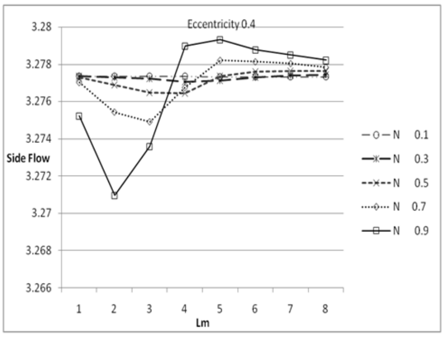
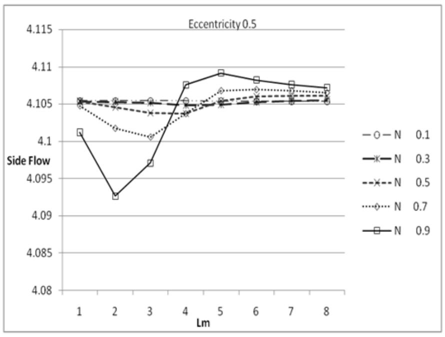


Figure 9



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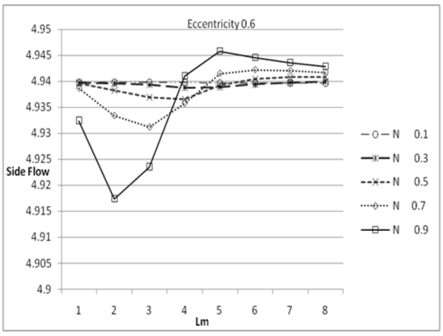

Figure 11

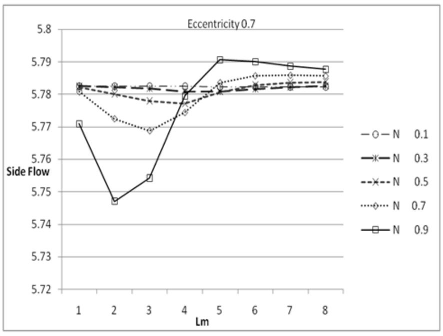

Figure 12

Note: Instead of N the value of N2 are shown in graph

CONCLUSIONS

The effect of micropolar lubricant on the load carrying capacity of a rigid circular bearing has been done. The results have been obtained by writing a program in MATLAB, considering the effect of coupling number and characteristics length.

It can be concluded that with micropolar fluids the load carrying capacity of a journal bearing increases considerably at higher coupling number and lower characteristic length.

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APPENDICES

Nomenclature

C	Conventional radial clearance (m)
C_m	Minor Clearance when journal and bearing geometric centers are coincident (m)
C_o, C_a, C_d	Coefficient of angular viscosities
F_f	Friction Force (N)
F_f	Non-Dimensional Friction Force (C/µ URL)F)
f	Friction Coefficient
h	Film Thickness (m)
L_m	Non-Dimensional Characteristic Length of Micropolar Fluid, L_m= C/A
N	Coupling Number, $N = (\mu_r/\mu + \mu_r)^{1/2}$
O	Bearing Center
O_j	Journal Center
P	Fluid Film Pressure (N/m^2)
P	Non-Dimensional Fluid Film Pressure ($(C^2/\mu UR)P$)
Q	Side Leakage Flow (m^3/s)
Q	Non-Dimensional Side Leakage Flow ($(6L/CUR^2)Q$)
R	Journal Radius (m)
U	Velocity of Journal (m/s)

v_x, v_y v_z Component of Lubricant Velocity in the x, y and z Directions (m/s)

X, Y, Z Cartesian Axes with Origin at Bearing Geometric Center

X_i, Y_i Coordinates of Journal Center

W Resultant of Load (N)

W Non-Dimensional Load $(C^2 / \mu ULR^2)W)$

W_x, W_y Non-Dimensional Load, Components in X and Y Direction

w_x, w_y, $W_z$microrotation Velocity Components about the Axes (l/s)

ξ Eccentricity Ratio

θ Angular Coordinate Measured from x-axis

θ_0^i ANGLE of Lobe Line of Centers

θ_1^i, θ_2^i Angles at Leading and Cavitating Edge of the Lobe

δ Preload of the Bearing (C'n/C)

ϕ Attitude Angle

μ Viscosity of the Newtonian Fluid (N s/m^2)

μ_r Microrotation Viscosity (N s/m^2)

Λ Characteristic Length of Micropolar Fluid (m), $\Lambda = (c_a + c_d/4\mu)^{1/2}$

ρ Lubricant Density (kg/m^3)

λ Aspect Ratio, Bearing Length to Diameter Ratio

λ_o Second Viscosity Coefficient (N s/m^2)

ω Angular Speed of the Journal (1/s)

I Subscript and Superscript for Lobe Designation

\- Superscript for Non-Dimensional Quantities